



## UNIVERSITY OF RUHUNA

### Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2026

Module Number: ME5305

Module Name: Refrigeration and Air-Conditioning  
(C-18)

[Three Hours]

[Answer all questions. Each question carries 10 marks]

**Note:** Provide neat sketches and state any reasonable assumptions made; Symbols have their usual meaning; Psychrometric chart and p-h chart for Ammonia are provided.

- Q1 a) Briefly explain **two** practical difficulties encountered when using air refrigeration systems. [2.0 Marks]
- b) Draw the  $p-v$  diagram and  $T-s$  diagram for the reversed Brayton cycle. Hence, prove that the Coefficient of Performance (C.O.P.) of the system can be expressed as follows.

$$C.O.P. = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

where  $r_p$  - compression or expansion ratio  
 $\gamma$  - isentropic index

- c) A Carnot refrigeration cycle absorbs heat at 270 K and rejects it at 300 K. [4.0 Marks]
- i) Calculate the C.O.P. of the refrigeration cycle. [1.0 Mark]
- ii) If the cycle is absorbing 1130 kJ/min at 270 K, how much work is required per second in kJ? [1.0 Mark]
- iii) If the Carnot heat pump operates between the same temperatures as the above refrigeration cycle, determine the C.O.P. of the heat pump. [1.0 Mark]
- iv) Determine the heat delivery (kJ/min) by the heat pump at 300 K if it absorbs 1130 kJ/min at 270 K. [1.0 Mark]
- Q2 a) Briefly explain **three** different industrial applications of vapour compression refrigeration cycles. [3.0 Marks]
- b) A vapour compression refrigerator uses methyl chloride (R-40) and operates between pressure limits of 177.4 kPa and 967.5 kPa. At entry to the compressor, the methyl chloride is dry saturated and after compression has a temperature of 102 °C. The compressor has a bore and stroke of 75 mm and runs at 8 revolutions

per second with a volumetric efficiency of 80%. The temperature of the liquid refrigerant as it leaves the condenser is 35 °C and its specific heat capacity is 1.624 kJ/kg K. The specific heat capacity of the superheated vapour may be assumed to be constant. Specific heat capacity of water is 4.187 kJ/kg K.

The relevant properties of methyl chloride are as follows:

| Saturation temperature<br>°C | Pressure<br>kPa | Specific volume<br>m <sup>3</sup> /kg |        | Specific enthalpy<br>kJ/kg |        | Specific entropy<br>kJ/kg K |        |
|------------------------------|-----------------|---------------------------------------|--------|----------------------------|--------|-----------------------------|--------|
|                              |                 | Liquid                                | Vapour | Liquid                     | Vapour | Liquid                      | Vapour |
| -10                          | 177.4           | 0.00102                               | 0.233  | 45.38                      | 460.76 | 0.183                       | 1.762  |
| 45                           | 967.5           | 0.00115                               | 0.046  | 132.98                     | 483.6  | 0.485                       | 1.587  |

i) Calculate the C.O.P. of the system.

[2.0 Marks]

ii) Determine the mass flow rate of the refrigerant.

[2.0 Marks]

iii) Determine the cooling water required by the condenser if its temperature rise is limited to 12 °C.

[2.0 Marks]

c) Draw the  $T-s$  diagram of the actual vapour compression refrigeration cycle.

[1.0 Mark]

Q3 a) What thermodynamic and operational requirements necessitate the use of a compound (multi-stage) vapor compression system in preference to a single-stage compression system?

[2.0 Marks]

b) A two-stage compression ammonia refrigeration system operates between overall pressure limits of 14 bar and 2 bar. The temperature of the desuperheated vapour and subcooled liquid refrigerant is limited to 30 °C. The flash tank separates dry vapour at 5 bar pressure, and the liquid refrigerant then expands to 2 bar. Calculate the C.O.P. of the machine and the power required to drive the compressor, if the mechanical efficiency of the drive is 80% and the load on the evaporator is 10 TR.

[6.0 Marks]

c) State the meanings of the terms: refrigerator, refrigerant, and refrigeration.

[2.0 Marks]

Q4 a) Draw the  $p-h$  diagram and calculate the power needed to compress 20 kg/min of ammonia from saturated vapour at 1.4 bar to a condensing pressure of 10 bar by two-stage compression with intercooling by liquid refrigerant at 4 bar. Assume saturated liquid to leave the condenser and dry saturated vapour to leave the evaporator.

[4.0 Marks]

- b) Two cooling machines are connected one after the other such that the heat rejected by the first unit becomes the input to the second. The first unit extracts heat from a reservoir maintained at  $127^{\circ}\text{C}$  at a rate of  $4\text{ kJ/s}$  and discharges it to an intermediate reservoir at an unknown temperature  $T$ . The second unit then absorbs this same heat from the intermediate reservoir and expels it to a high-temperature reservoir at  $1227^{\circ}\text{C}$ . Assuming both machines operate with identical coefficients of performance, determine:
- i) The temperature of the intermediate reservoir [1.5 Marks]
  - ii) The C.O.P. of each machine [1.0 Mark]
  - iii) The heat rejected to the  $1227^{\circ}\text{C}$  reservoir [1.5 Marks]
- c) Draw the  $p$ - $v$  and  $T$ - $s$  diagram for the reversed Carnot cycle. [2.0 Marks]
- Q5 a) An air-conditioning system draws a mixture of return air and fresh outdoor air at a volumetric flow rate of  $39.6\text{ m}^3/\text{min}$  into a cooling coil. The air enters the coil at a dry-bulb temperature of  $31^{\circ}\text{C}$  and a wet-bulb temperature of  $18.5^{\circ}\text{C}$ . The coil has an effective surface temperature of  $4.4^{\circ}\text{C}$  and is sized to provide a cooling capacity of  $12.5\text{ kW}$  under these inlet conditions. Determine the dry and wet bulb temperatures of the air leaving the coil and the bypass factor. [5.0 Marks]
- b) Two air streams are combined: one is recirculated air flowing at  $800\text{ m}^3/\text{min}$  with a dry-bulb temperature of  $22^{\circ}\text{C}$  and a dew point of  $10^{\circ}\text{C}$ , while the other is fresh air at  $300\text{ m}^3/\text{min}$  with a dry-bulb temperature of  $30^{\circ}\text{C}$  and 50% relative humidity. Determine the properties of the resulting mixture, including its enthalpy, specific volume, humidity ratio, and dew point temperature. [5.0 Marks]



# PSYCHROMETRIC CHART NORMAL TEMPERATURES STANDARD ATMOSPHERIC PRESSURE (760 mm Hg)

(Below 0 °C Properties and Enthalpy Deviation lines are for ice)

